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TABLES

FOR THE DETERMINATION OF THE ROCK-FORMING MINERALS

F. LŒWINSON-LESSING

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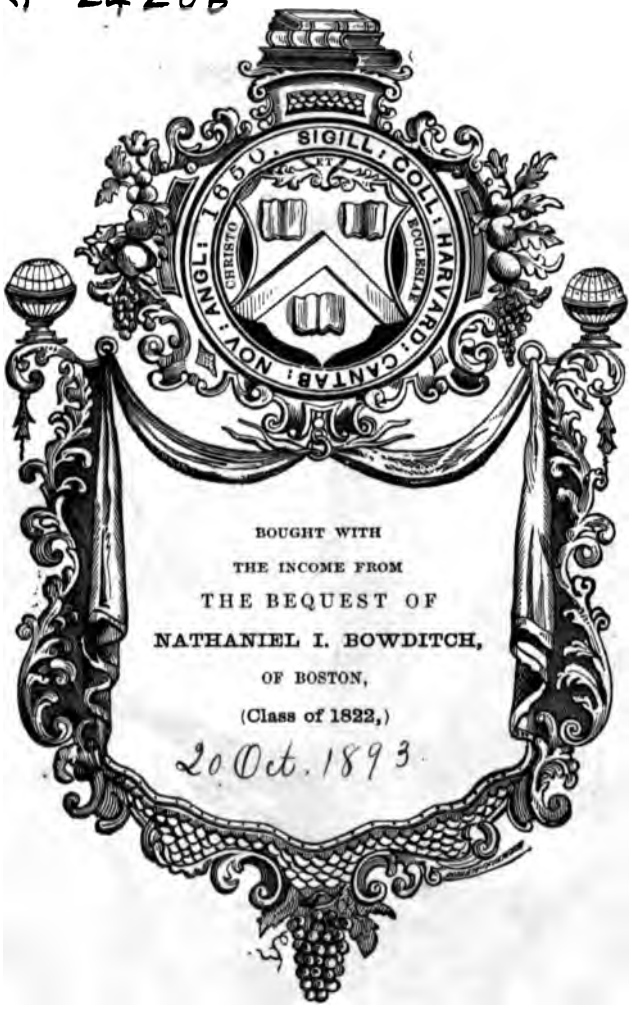

BOUGHT WITH
THE INCOME FROM
THE BEQUEST OF
NATHANIEL I. BOWDITCH,
OF BOSTON,
(Class of 1822,)
20 Oct. 1893

TABLES FOR THE DETERMINATION

OF THE

ROCK-FORMING MINERALS

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OF THE

ROCK-FORMING MINERALS

COMPILED BY

F. LŒWINSON-LESSING

PROFESSOR OF GEOLOGY AT THE UNIVERSITY OF DORPAT

TRANSLATED FROM THE RUSSIAN BY

J. W. GREGORY, B.Sc., F.G.S.

OF THE BRITISH MUSEUM (NATURAL HISTORY)

WITH A CHAPTER ON THE PETROLOGICAL MICROSCOPE BY

PROF. GRENVILLE A. J. COLE, M.R.I.A., F.G.S.

London

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1893

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PART I. INTRODUCTORY

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THERE is probably no branch of geology in which an unaided student has more difficulty in making a start than in the microscopic study of rocks. This is especially to be regretted, as it is now recognised that this method of research is indispensable for any accurate work on the igneous rocks. Many a resident on the great volcanic plateaux of India, Africa, or America, or on the vast tracts of gneiss and schists which form such a large proportion of the earth's crust, is debarred from geological work by the difficulty of identifying minerals under the microscope. Thus our knowledge of many of these areas is very deficient, for they are only known by occasional rapid traverses; and the problems they present are so complex that they can only be fully worked out by a resident or by a thorough survey.

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MKONCUMBI, BRITISH EAST AFRICA,
2nd December 1892.

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applied have been used. The system of determining a mineral by several different lines of examination will, it is hoped, further prove of educational value by thoroughly impressing its characters on the minds of students.

Though the needs of the elementary student have been kept in view in the main, the author hopes that the tables will prove of service to those engaged in original research. He also expresses his indebtedness to the works of Hussak, Rosenbusch, and Michel Lévy and Lacroix, and reiterates that reference must be made to these, in the case of the rarer minerals met with as accessories in rocks.

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St. Petersburg, 1891.

INTRODUCTION

In the attempt to determine any mineral by the aid of these tables, it is absolutely necessary that they should be used on a strictly systematic plan. Only experienced petrographers ought to trust to anything in the nature of short cuts. If a mineral is assigned to the wrong series, especially in the major divisions, serious mistakes are inevitable.

A section of a rock must first be examined by the aid of **ordinary transmitted light**; by this the transparent and opaque constituents can be at once separated, and the latter noted for subsequent examination with reflected light. In the case of the transparent minerals, we can at once determine their colours, form, cleavage, and the presence or absence of inclusions; we may also note whether the mineral shows any signs of special structure, such as whether it is fibrous or zonal, and whether it has been fractured or has been formed as a pseudomorph.

When all these characters have been noted, the analyser and polariser should be inserted, the nicols crossed, and the mineral thus examined in simple **polarised light.** This enables the singly refracting minerals in the slide to be separated from those which are doubly refracting. The latter become light and dark alternately, four times during a complete rotation of the stage of the microscope, while they show interference-colours more or less clearly. The singly refracting minerals, on the other hand, remain dark throughout the rotation. This method of examination also reveals whether a crystal is simple or twinned, the direction of the axes of elasticity (by means of the determination of the directions of extinction by a stauroscope, Bertrand's eye-piece, or quartz plate), and the crystalline system to which the

mineral belongs. To settle these points, the behaviour of the mineral under polarised light must be examined in greater detail.[1]

In the first place, a mineral may remain dark through the complete rotation of the stage of the microscope; such minerals are *isotropic.* They may belong either to a singly refractive substance, such as an *amorphous* glass or a crystal of the *cubic* system; or else they may be sections of a *uniaxial* doubly refractive mineral cut at right angles to the optic axis. The value of the mean refractive index may be judged by the aspect of the surface of a section of a mineral; thus, if its index of refraction is higher than that of the Canada Balsam round it, the surface appears raised and rough. The next point to be determined is the direction of the extinction under crossed nicols. This may be *straight, i.e.* parallel to the crystallographic axes, or *oblique, i.e.* inclined at some definite angle which is constant for the same mineral. If some of the sections parallel to the principal axis have straight extinctions it is necessary to inquire whether all such sections of the mineral agree in this respect, in which case the mineral belongs to the *rhombic* system; but if some of these sections have straight extinctions and some oblique, then the mineral belongs to the *monoclinic* system.

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In conclusion it must be pointed out that though in rock-

sections all these characters cannot always be used, the systematic course of determination should be followed as far as possible. The synoptical table, however, enables one to form a hasty approximate idea of the affinities of a mineral. This identification should, however, always be checked by the course of examination previously recommended.

THE PETROLOGICAL MICROSCOPE

THOUGH the following tables deal solely with the characters of rock-forming minerals as seen in thin sections under the microscope, it should be remembered that the section and the rock from which it has been cut should always go side by side in any determinative investigation, and that the microscopic examination of the powdered rock, or of cleavage-flakes broken from some of its constituents, may often give results strikingly confirmatory of, or even superior to, the suggestions gained from the thin section.

The simpler methods of observation employed in examining rock-sections under the microscope have been outlined in the preceding introduction; it only remains to point out the special features of the ordinary petrological microscope.

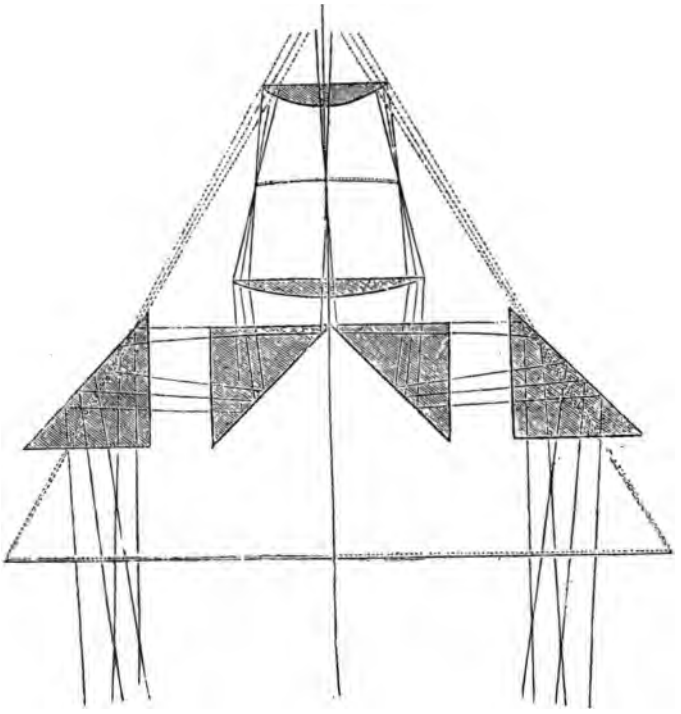
Low power objectives are fully as necessary as higher ones, and often the structure of a rock and the association of special minerals are best seen with a three-inch objective, magnifying perhaps some 15 diameters. The microscope should therefore be capable of taking such a power; few ordinary instruments, with rack and pinion adjustment, focus back much beyond the requirements of a 2-inch.

It should be possible to centre the objective by means of screws, or to centre the stage itself, in every instrument in which a rotating stage is used.

When light is sent through the section from below by means of the mirror, the minerals are said to be viewed by **transmitted light**; when this is cut off, and light, often concentrated by a condenser, is thrown upon the upper surface of the section and is reflected from it, the section is viewed by **reflected light.**

Prof. A. Inostranzev has invented a **comparative camera,** which

is especially useful in investigations with reflected light. The annexed figure illustrates its construction. The author's description is as follows[1]:—"This apparatus serves, so to speak, as a means of elongating and bending through a right angle two adjacent microscopes, so that both images can be brought together into a field of vision in the centre of the camera. In the outer angles of the camera are two reflecting prisms, or merely two small mirrors, which cause the rays from the



microscopes to bend through a right angle. In the central part of the camera, beneath the opening for the eye-piece, are two additional prisms, so placed as to throw the images upwards. The comparative camera is placed over two adjacent microscopes from which the eye-pieces have been removed, and one of the eye-pieces is inserted in the tube above the central prisms. In the eye-piece of the camera we then have a circular field, divided into halves by a delicate line. One half of this

[1] Neues Jahrbuch für Mineralogie etc., 1885, Bd. ii. p. 96.

field belongs to one microscope, one half to the other. If both objects" [placed for comparison under the microscopes] "are identical in lustre and colour, both images appear identical, and the field of vision is therefore completely uniform. If there is the slightest difference in the colour of the objects, the divisional line shows itself at once, the two halves of the field appearing clearly different."

Cross-wires are necessary in the eye-piece of a petrological microscope, when one wishes to bring an object into the centre of the field, and to measure crystallographic angles or angles of extinction.

A **polariscope** must be attached, in such a way that each of the Nicol's prisms can be easily brought into action and thrown out again.

The **analyser,** or upper nicol, may be slipped on and off over the eye-piece, or brought into position there on a swinging arm; or it may be capable of sliding in and out in a slot of the microscope-tube a little above the objective. The latter arrangement allows of a larger field being obtained than with an "eye-piece analyser."

The **polariser,** or lower nicol, should be brought into position centrally under the stage by means of its insertion in a collar at the end of a rotating arm.

A system of **converging lenses,** practically the old "sub-stage condenser" in a simple form, slips into the opening of the stage above the polariser, and is used in the determination of the uniaxial or biaxial character of minerals. It is preferable to have the converging arrangement fitted into the stage itself, rather than resting on and dependent on the polariser, since ordinary transmitted light can then be condensed upon an object when polarised light is not required.

The simplest method of utilising convergent polarised light is to employ a high power of the microscope, cross the nicols, remove the eye-piece, and look down the tube from a little distance. The characteristic "optical picture" of "rings and brushes" can then be very brightly and sharply seen. This is the **method of Von Lasaulx. Bertrand's method** is to insert a lens of low magnifying power in a slot of the microscope-tube below the eye-piece; the eye-piece is retained, and a magnified image of the rings and brushes can thus be studied.

The petrological microscope must have a **rotating stage,** with a

graduated edge for measuring the angle through which it is turned during any particular observation; or, as in Mr. Dick's pattern of microscope, made by Messrs. Swift and Son of London, the nicols when crossed must be capable of being rotated, and yet retained in that relation to one another, together with the cross-wires of the eye-piece. In practice, the whole eye-piece, carrying the analyser, is made in the latter method to rotate together with the polariser, the amount of rotation being measurable as in the case of a rotating stage.

In determining the position of extinction of a mineral-section, a **quartz plate** is sometimes used. This is inserted in a slot above the objective, and gives a coloured field between crossed nicols. A doubly refracting mineral-section placed on the stage appears of another tint upon this field. But when, by rotation, its position of extinction is reached, *i.e.* when it has no effect upon the rays emerging from the polariser, only the characteristic interference-colour due to the quartz plate is seen. This renders the determination of the exact position of extinction more certain than when, as is ordinarily done, the position of greatest darkness is estimated by the eye.

A further refinement in this direction is what is known as the **Bertrand eye-piece,** of which the following description has been given. "The quartz plate is made of four separate sectors, meeting at the centre of the field, two of them, through circular polarisation, rotating the ray to the right, and the alternate ones to the left, the four having between crossed nicols precisely the same tint. A crystal placed with regard to the polariser in any other position than that of extinction imparts opposite colours to the alternate sectors when brought into the centre of the field; and its vibration-planes are parallel to the diagonals of the lower nicol when the colour of the four sectors is restored."[1]

A **quartz wedge** is of great value for determining which of the principal directions of elasticity in a mineral-section is that of maximum and which of minimum elasticity, and consequently for the determination of the optical sign, especially in uniaxial crystals. The wedge is cut so that its longer axis is parallel to the axis of least elasticity of the original quartz crystal; when inserted on the level of the stage, or under the eye-piece analyser, with its longer direction in a position of 45° to the diagonals of the nicols, it should show a

[1] Cole, *Aids in Practical Geology*, p. 132.

gradation of tints from the lowest grey of the first order up to, say, colours of the fourth or fifth order. When, by means of the positions of extinction, the two principal directions of elasticity in a crystal-section have been found, these directions are brought to a position of 45° with the diagonals of the nicols, which remain crossed. The quartz wedge is then inserted, its longer direction running parallel to one of the principal elasticity-directions of the mineral-section. If, on continued insertion, the interference-colour, as given by the wedge, is heightened where it lies above the crystal, the direction in question is that of least elasticity in the section; if, on the other hand, the colour is lowered, and finally "compensation" occurs, a phase of colour-extinction being gone through, the direction is the reverse of that of the long axis of the quartz wedge, *i.e.* it is that of maximum elasticity.

The application of this method to prismatic sections of uniaxial crystals is obvious; in these the principal axis of form is always one of the axes of elasticity of the crystal, the direction perpendicular to this being in all prismatic sections that of opposite elasticity. But in the rhombic system, while the vertical axis is always an axis of elasticity, it may be either maximum or minimum without any conclusion being possible as to the optical sign. It must be remembered, indeed, that the **optical signs,** *positive* and *negative,* have very different meanings in the case of uniaxial and biaxial crystals. In the former case a crystal is negative when the principal axis of form is that of greatest elasticity; a biaxial crystal is negative when its axis of greatest elasticity bisects the acute angle between the optic axes. Reference must be made to more detailed works on the subject to learn how the bisectrices, or axes of maximum and minimum elasticity, which lie always in the optic axial plane, are related to the axes of form in any particular biaxial crystal. The positive or negative character thus becomes a point of less importance for biaxial crystals. One may determine the position of the optic axial plane by means of convergent polarised light; but only in refined researches is it necessary to know which is the acute and which the obtuse angle between the optic axes.

To sum up, for the examination of transparent minerals as to *form, cleavage, and schillerisation-planes,* we require transmitted light, and

cross-wires in the eye-piece, with means of measuring the rotation of the stage, or, in Mr. Dick's instrument, of the eye-piece and cross-wires. For the examination of the value of the mean *refractive index* and *colour*, we similarly require transmitted light.

For the determination of *pleochroism*, we require the polariser; for observing *isotropism* or *anisotropism*, both polariser and analyser, duly crossed. *Twin-crystals*, simple or polysynthetic, will of course show alternate bands of colour corresponding to their components. In anisotropic minerals the interference-colours will be relatively high when the double refraction is strong, and low when the double refraction is weak. The terms "bright" and "dull" colours may be sometimes used in description; but the position of the colours in Newton's scale, and the fact that they are higher or lower than those given by some other and known mineral in the same rock-section, are the points to be relied upon in observations between crossed nicols.

In determining *angles of extinction*, the quartz plate or Bertrand eye-piece may be useful in addition to the polariscope, cross-wires, and means of measuring rotation.

In investigating the *optical sign*, a quartz wedge is required.

Lastly, for distinguishing *uniaxial* from *biaxial* crystals, we use the crossed nicols, the converging lens with the eye-piece removed, or the lens supplemented by a magnifier slipped in between the analyser and the eye-piece.

PART II. TABLES

TABLE II

THE DETERMINATION OF MINERALS BY THE AID OF POLARISED LIGHT

EVEN the most casual microscopic examination of a thin section of any crystalline rock enables its constituents to be classified into two groups, the opaque and the transparent, and the latter to be subdivided into the coloured and the colourless. It is therefore convenient to first apply this method of examination. In the case of the coloured minerals they can be at once grouped according to their tints, as is done in the "Synoptical Table." With the colourless minerals, however, it is necessary to rely on their morphological characters, such as their occurrence in the form of grains, flakes, tabular crystals, etc.; these characters are applied in Table No. III. Colour alone, however, cannot be trusted, and ordinary polarised light must therefore be used to check the conclusions suggested by the Synoptical Table. It is usually possible to verify the determination without the aid of more advanced optical methods, such as refraction or dispersion.

The following abbreviations are used in this Table:—

c = Cubic.	− = Negative.
p = Prismatic (tetragonal).	*r* = Rhombic.
h = Hexagonal (rhombohedral).	*m* = Monoclinic.
am = Amorphous.	*a* = Triclinic (asymmetric).
+ = Positive.	

I. OPAQUE MINERALS[1]

a. **Metallic.**

a. Soluble in hydrochloric acid.

1. Dark bluish black, metallic lustre; occurring as aggregates, grains, octahedra, or

[1] In the determination of the few opaque minerals which occur as normal constituents in crystalline rocks reflected light must be employed, as it is only thus possible to recognise their colour and lustre. Professor A. Inostranzev has designed a "comparative camera," which may be conveniently employed for this purpose, and gives the test more precision. It is described in his *Gheologiè*, 2nd ed. vol. v. p. 284. His figure and a translation of the description of the method are given in Part I. Chapter IV.

cubes (the last two usually give rise to triangular, square, oblong, or rhombic cross sections)	MAGNETITE,[1] *c.*
2. Black metallic lustre; occurs in hexagonal or irregular plates; if translucent, then of a blood-red hue	HÆMATITE, *h.*
3. Lustre that of metallic iron; reactions of iron with sulphate of copper . .	METALLIC IRON, *c.*
β. Insoluble in hydrochloric acid.	
4. Lustre of bronze or bath metal . .	MAGNETIC PYRITES, *h.*
5. Black, blackish-brown metallic lustre. Acicular crystals; flakes R and oR; grains. Soluble with difficulty in hydrochloric acid	ILMENITE, *h.*
6. Black metallic lustre. Absolutely opaque; hexagonal flakes. Disappears on heating to redness	GRAPHITE, *h.*[2] (Youngite, *am*).
***b.* Non-metallic.**	
1. Black grains, stains, and dust: on heating to redness rock containing it, it loses its colour	CARBONACEOUS MATTER, *am* (Bitumen).
2. Cloudy grey-white small lumps and aggregations	KAOLIN.
3. Cloudy grey-brown semi-transparent pseudomorphs after ilmenite	LEUCOXENE.

II. SEMI-TRANSPARENT MINERALS

For hæmatite, kaolin, and leucoxene, see *ante;* for rutile, see below; for the remainder, see Table V. Part A.

III. TRANSPARENT MINERALS

A. COLOURLESS

I. In crystalline rocks always show crystal-outlines.

1. Polarisation colours bright.

a. Extinction straight.

[1] Titanoferrite may be distinguished from magnetite by micro-chemical methods (it giving the reactions of titanium), and from ilmenite by its crystalline form and behaviour in acids.

[2] Graphite may be included among the metallic minerals owing to its well-developed metallic lustre.

α. Short prismatic crystals with terminal pyramids	ZIRCON, *p.*
β. Filaments not ending in definite terminal planes; the rods often appear jointed	SILLIMANITE, *r.*
b. Extinction oblique.	
α. Cleavage along ∞P∠87°. Long filamentous prisms; soluble in hydrochloric acid (+) . .	WOLLASTONITE,[1] *m.*
β. Cleavage along ∞P∠124°. Long narrow prisms (filaments) often split at the ends. Not soluble in hydrochloric acid (−) . .	TREMOLITE, *m.*
2. Polarisation colours dull, bluish grey.	
a. Extinction straight.	
α. Long prismatic crystals often divided transversely; hexagonal sections isotropic. Uniaxial. Soluble in HCl; reactions of phosphoric acid	APATITE, *h.*
β. Similar prisms; hexagonal, transverse sections, not isotropic. Biaxial. With difficulty soluble in HCl	ZOISITE,[2] *r.*
γ. Tile-like aggregates of hexagonal flakes	TRIDYMITE, *h.*
b. Extinction oblique.	
α. Minute short prisms, sometimes twinned	FELSPATHIC MICROLITHS,[3] *m* and *a.*

[1] Aggregations of wollastonite are, in the absence of cleavage, with difficulty separable from filamentous aggregations of zeolites, such as scolecite.

[2] Aggregates of zoisite, such as those in saussuritic felspars, often greatly resemble acicular filamentous zeolites. The higher polarisation colours of the latter, and their easy solubility in acids, readily enable these to be distinguished; scolecite, desmine, and stilbite may be separated by their oblique extinction. From the rhombic natrolite zoisite may be distinguished by its hard salient surface (an appearance due to its high refractive index) and the much larger size of the grains, as well as by its crystallographic characters.

[3] The different species of plagioclase may be distinguished from one another and from orthoclase by the angle of extinction and micro-chemical tests; see Fouqué and Lévy, *Minéralogie Micrographique*, and Michel Lévy and Lacroix, *Tableaux des Minéraux des Roches.*

II. In crystalline rocks, occurring as crystalline grains or crystals.

1. Polarisation colours bright.

a. Optical sign positive.

α. Extinction straight.

Uniaxial.

1. Water-clear; often with abundant fluid cavities. If crystalline, occurs as double pyramids with or without prism faces. Acids, except hydrofluoric, have no action upon it. Neither twinning nor cleavage . . QUARTZ, *h.*

Biaxial.

2. A shagreen surface; alteration into serpentine and limonite very characteristic. Soluble in HCl. Sections characteristically hexagonal. No cleavage. OLIVINE, *r.*

3. Cleavage along $\infty P \angle 92°$. Often twinned along $\infty \breve{P} \infty$. Vertical striation. (The polarisation colours far lower than in the preceding mineral.) Sections octagonal . . ENSTATITE, *r.*

β. Extinction oblique.

1. Polysynthetic twinning causing a banded appearance; a second twinning may occur transverse to the first . . . . . PLAGIOCLASE, *a.* (especially Labradorite).

2. Prismatic cleavage along $\infty P \angle 87°$. Often twinned along $\infty P \infty$. Sections characteristically hexagonal or octagonal. Usually not quite colourless, but with a faint yellow tinge . . . AUGITE, *m.*

b. Optical sign negative.

α. Extinction straight.

1. Thick flakes and plates with a very perfect cleavage along oP. Aggregations of small flakes. Very bright polarisation colours (sometimes iridescent) . . MUSCOVITE,[1] *m.*

[1] Muscovite is sometimes of a light green colour.

2. Long lath-shaped crystals; rough surface. Cleavage prismatic . ANDALUSITE, *r.*
3. Long lath-shaped forms, grains, or crystals (∞ P, ∞ P ∞, P). Cleavage along ∞ P ∞. When dissolved in hydrochloric acid leaves an insoluble powdery residue of SiO_2. Some sections may be isotropic . SCAPOLITE,[1] *p.*

β. Extinction oblique.

1. Simple twinning on the Carlsbad, Baveno, or Manebach types. Occurring in tabular crystals; sections often hexagonal. Angle of extinction small—about 5° in reference to the direction oP : (∞ P ∞).
   a. Sections appear dusty through kaolinisation (or sometimes through development of flakes of Muscovite). Occur as crystals or grains. Often appear coloured in ordinary light owing to the presence of oxide of iron . . . ORTHOCLASE, *m.*
   b. Water-clear crystals; often with zonal structure. Numerous glass inclusions . . SANIDINE, *m.*
2. Polysynthetic twins in the form of a system of more or less broad parallel bands; there may be either one system or two, transverse to one another . . . LABRADORITE, *a.*
3. Polarisation colours extremely bright. Occurs as long prisms, usually without terminal basal planes; often resembles sillimanite, from which it may be distinguished by its optical character being −, and its crystalline system . . DISTHENE, *a.*

2. No bright polarisation colours.
   a. Crystalline system, cubic.

[1] Meionite may be distinguished from scapolite by its chemical constitution. Cuseranite, which is very rarely met with, is also allied to scapolite.

Decomposed by HCl.

- *a.* Complex twin structure. Optical anomalies (*e.g.* doubly refracting). Granular inclusions regularly arranged. Rounded grains or octagonal sections . . . . LEUCITE,[1] *p.*
- *β.* Occurs as small tabular crystals and grains; sections are usually rectangular. Cleavage along the planes ∞P and oP. When decomposed in HCl precipitates SiO_2. Characteristic "peg" structure . . MELILITE, *p.*
- *b.* Crystalline system hexagonal (hexagonal sections isotropic).
  - *a.* Complex twinning. Rhombohedral cleavage. When decomposed by acid, effervesces and gives off CO_2. High colours under crossed nicols . . . . . CALCITE, *h.*
  - *β.* Occurring as grains or tabular prismatic crystals. Polarisation colours bluish grey. Gives reactions of NaCl . . . . . NEPHELINE, *h.*

III. In crystalline rocks always occur in the form of grains.

1. Occurs as thick crystalline grains. A "checked" structure due to the crossing of two sets of laminæ. The angle of extinction on oP is 15°, measured from the cleavage ∞P̆∞ . . . . . MICROCLINE, *a.*
2. Granular aggregates; see synoptical table.

B. COLOURED

I. Always show crystal-outlines.

Pleochroic.

- *a.* Long hexagonal prisms; often in radial aggregates. Blue or green (−) . . . TOURMALINE, *h.*
- *b.* Colour light or dark brown. Cross-shaped twins (+). Rarely occurring as grains . STAUROLITE, *r.*

[1] Leucite has the external form and habit of a cubic crystal, but the optical properties show that it must be regarded as a mimetic twin, or a crystal of some other system which has thus acquired a higher degree of symmetry.

II. Either as crystals or crystalline grains.

a. Polarisation colours bright.

a. Pleochroic.

Extinction oblique.

1. Prismatic cleavage $\infty P \angle 124°$.
   - *a.* Green or brown . . . . HORNBLENDE, *m.*
   - *b.* Blue . . . . . GLAUCOPHANE, *m.*
2. Sky-blue colour. Occurring as long prismatic crystals or grains. Cleavage along $\infty \bar{P} \infty$ and $\infty \breve{P} \infty$. DISTHENE, *a.*
3. Lemon-coloured. Usually granular aggregations or pseudomorphs. If crystalline, as small prisms extended along the orthodiagonal (−) EPIDOTE, *m.*
4. Dark green, or sometimes dark blue. Occurring as large plates. Double or triple twins on the hemipyramid (+) . . . . . CLINOCHLORE,[1] *m.*

Extinction straight.

5. Violet-blue colour; twinned repeatedly; alteration into pinite very characteristic . . . . CORDIERITE, *r.*
6. Flesh or rose coloured tabular crystals, often crowded with inclusions . ANDALUSITE, *r.*
7. Occurring as small prisms or grains, or broad flakes; brown in colour. Numerous inclusions of dark flakes or needles. Prismatic cleavage $\infty P \angle 92°$ . . . . . HYPERSTHENE, *r.*
8. Dark brown octagonal sections. Flakes. Prismatic cleavage $\infty P \angle 124°$. ANTHOPHYLLITE, *r.*
9. Large (occasionally small) flakes and tabular crystals of a brown or green colour. Absorption. Well developed cleavage along oP . . BIOTITE, *m.*

β. Pleochroism not observed (rarely very weak).

a. Extinction oblique.

1. Colour, typically yellow, but it may be violet, rose-red, or green.

[1] Except for clinochlore, of which the determination is easy, the only chlorite likely to be met with as crystals in crystalline rocks is the rhombic pennine. The remainder of the chlorites occur as aggregates, secondary products, and pseudomorphs, and are determinable only with difficulty.

Occurs as octagonal, hexagonal, or other sections. Twinning along $\infty P \infty$. Prismatic cleavage $\infty P \angle 87°$ . . . . . AUGITE, *m.*

b. Extinction straight.

1. Sometimes weak pleochroism. Prismatic cleavages cross each other at $\angle 92°$. Dull polarisation colours. Sections occur as long prisms and resemble those of the preceding mineral. Bronze coloured . . BRONZITE, *r.*
2. Dark yellow crystals identical with olivine (see p. 28) . . . FAYALITE, *r.*
3. Broad, dark green tabular crystals and cleavage flakes; basal cleavage very perfect (see p. 28) . . MUSCOVITE, *m.*

b. No bright polarisation colours.

a. Extinction straight.

1. Black polyhedra; rarely occurring as grains; honey-yellow or dark brown in colour. Geniculate twinning very characteristic. (Sometimes semi-transparent with metallic lustre) . . RUTILE, *p.*
2. Small sharp prisms; dark lavender-blue in colour . . . . . ANATASE,[1] *p.*
3. Honey-yellow flakes or grains; sometimes rectangular in section. Cleavage prismatic. Soluble in HCl. "Peg" structure very characteristic . MELILITE, *p.*
4. Green, brown, or yellow in colour, with a greasy lustre. Reactions of NaCl. Rarely granular . . . . ELÆOLITE, *h.*

β. Extinction oblique.

1. Dark brown very salient grains. Wedge-shaped in section. Polarisation colours often indistinguishable from those of the mineral itself . . . . TITANITE, *m.*

[1] See further under leucoxene.

III. Always granular.

1. Fibrous grains stained by limonite. Decomposed with evolution of CO_2 . . . CANCRINITE,[1] *h.*
2. Grass-green grains with prismatic cleavage at $\angle 87°$. Large angle of extinction; about 39° in sections parallel to ($\infty P \infty$) . . OMPHACITE, *m.*
3. Granular aggregates; see synoptical table.

[1] The small proportion of potash and the inclusion of $CaCO_3$ among its constituents enable cancrinite to be readily distinguished from nepheline by chemical means.

TABLE III

THE APPLICATION OF THE MORPHOLOGICAL CHARACTERS OF MINERALS

In many cases only broken outlines of sections of crystals can be seen when a thin section is examined under the microscope. In such cases it is convenient to refer to the following tables :—

Table II has given the characters of the crystalline grains, and the following ones give some valuable supplementary methods of determination. The following six morphological types include the principal variations, and are sufficiently characteristic :—

A. Tabular Crystals.
B. Minute Needles and Microscopic Prisms.
C. Broad Tablets.
D. Small Flakes.
E. Filaments and Filamentous Fibres.
F. Aggregates.

A. Tabular Crystals

I. Colourless.

1. Polarisation colours dull grey or dark blue.
   - *a.* The hexagonal transverse sections isotropic (soluble in HCl ; transversely jointed).
     - *α.* Crystals prismatic ; usually short, but rarely long. Reactions of NaCl . . Nepheline, *h.*
     - *β.* Crystals prismatic ; long. Reactions of P_2O_5 . . . . . Apatite, *h.*
   - *b.* Hexagonal transverse sections not isotropic. Surface appears much raised. Cleavage along $\infty \bar{P} \infty$ . . . . . Zoisite, *r.*
2. Polarisation colours bright.
   - *a.* Extinction straight (prismatic cleavage).
     - *α.* Uniaxial. Transverse octagonal sections isotropic . . . . Scapolite, *p.*
     - *β.* Biaxial.
       1. Optical sign positive . . Enstatite, *r.*
       2. „ „ negative . . Andalusite, *r.*

b. Extinction oblique.

α. Prismatic cleavage along $\infty P \angle 87°$.

1. Insoluble in HCl . . . SAHLITE, *m* (colourless augite).
2. Soluble in HCl more quickly when acicular than when tabular . . . . WOLLASTONITE, *m*.

β. Cleavage along oP, $\infty P \infty$, or ($\infty P \infty$).

1. Some sections give straight extinctions; simple crystals, or simple (never repeated) twins . ORTHOCLASE, *m*.[1]
2. Sections never give straight extinctions; polysynthetic twins PLAGIOCLASE, *a*.[2]

γ. Cleavage along $\infty \breve{P} \infty$ and $\infty \bar{P} \infty$. DISTHENE, *a*.[3]

II. Coloured.

1. Not Pleochroic.

a. Cleavage along $\infty P \angle 87°$; green, yellow, bluish-brown, or rose-coloured . . AUGITE, *m* (Diopside).

2. Slightly pleochroic.

a. Extinction straight. $\infty P \angle 92°$; dark brown or dark yellow . . . BRONZITE, *r*.

b. Extinction oblique: $\infty P \angle 87°$.

α. Large extinction angle, about 39° . AUGITE, *m*.

β. Small „ „ „ 2° to 7°, containing soda; brown or yellow . ACMITE, *m*.

3. Very pleochroic.

a. Extinction straight.

α. Uniaxial. Transverse sections isotropic.

1. Green, yellow, or rose-coloured . TOURMALINE, *h*.

β. Biaxial.

2. Flesh- (or rose-) coloured. Cleavage along ∞P . . . ANDALUSITE, *r*.
3. Brown; characteristic cross twins STAUROLITE, *r*.

b. Oblique extinction.

α. Prismatic cleavage $\infty P \angle 124°$.

[1] Orthoclase differs from sanidine only in the freshness of the latter mineral, which therefore does not appear altered, or dusty.

[2] On the determination of the plagioclases see footnote on p. 27.

[3] Minute colourless prisms of disthene can with difficulty be separated from sillimanite (determine crystalline system by Tables IV. and V.)

1. Brown, green . . . . HORNBLENDE, *m.*
2. Lavender or indigo blue . . GLAUCOPHANE, *m.*

β. Prismatic cleavage ∞P∠87.° Brown, green . . . . . ACMITE, *m.*

γ. Cleavage along $\infty \breve{P} \infty$ and $\infty \bar{P} \infty$. Blue . . . . . DISTHENE, *a.*

B. NEEDLES AND MICROSCOPIC PRISMS

I. Colourless.

1. Polarisation colours dull, bluish-brown.
   - *a.* Extinction straight. Hexagonal sections isotropic.
     - α. Long prismatic crystals transversely jointed. Reactions of P_2O_5 . . APATITE, *h.*
     - β. Short (rarely long) prismatic crystals. Reactions of NaCl . . . NEPHELINE, *h.*
   - *b.* Extinction oblique; sometimes twinned parallel to the long edges . . . FELSPATHIC MICROLITHS, *m* and *a.*[1]

II. Coloured.

a. Extinction straight.

α. Not pleochroic. Dull polarisation colours. Characteristic geniculate twins. Colours black, dark brown and honey-yellow (small needles are opaque) . . . RUTILE, *p.*

β. Strongly pleochroic. Bright polarisation colours.

1. Colour brown. Prismatic cleavage ∞P∠92°. Development of minute plates and angular inclusions along certain planes (schillerisation) very characteristic . . . HYPERSTHENE, *r.*
2. Lemon-yellow in colour; rough surface EPIDOTE, *m.*
3. Dark brown or dark green. Absorption. Very perfect cleavage along oP . . . . . BIOTITE, *m.*

b. Oblique extinction. Dark green, dark brown (sometimes almost colourless). Large angle of extinction, about 39°. Not pleochroic . AUGITE, *m.*

[1] See footnote 3, p. 27.

C. Broad Tablets

I. Colourless.

a. Extinction straight.

1. Dull bluish-brown polarisation colours. Soluble in HCl . . . . . NEPHELINE, *h.*

2. Bright polarisation colours.

   α. Shagreen surface. No cleavage. Soluble in HCl. Characteristic alteration into serpentine or limonite . . . . . OLIVINE, *r.*[1]

   β. Very perfect basal cleavage . . MUSCOVITE, *m.*[2]

   γ. Prismatic cleavage $\infty P \angle 92°$. Vertical striation . . . . . ENSTATITE, *r.*

b. Extinction oblique.

1. Cleavage along oP and $(\infty P \infty) \angle$ about 90°

   α. Simple twinning along the Carlsbad, Baveno, or Manebach types . . ORTHOCLASE, *m*[3] (Sanidine).

   β. Cross-hatched structure (extinction 15° on basal pinacoid) . . MICROCLINE and PERTHITE, *a.*

   γ. Polysynthetic twinning. One or two perpendicular transverse systems of parallel lines and more or less broad bands . . . . PLAGIOCLASE, *a.*[4]

   δ. Prismatic cleavage $\infty P \angle 87°$. Large angle of extinction, about 39° . AUGITE, *m.*

II. Coloured.

a. Extinction straight.

1. Strongly pleochroic.

   α. Brown or dark green. Absorption. Very perfect basal cleavage . . BIOTITE, *m.*

   β. Brown. Prismatic cleavage $\angle 92°$. Characteristic inclusions of needle-like angular flakes . . . HYPERSTHENE, *r.*

   γ. Bluish-brown; soluble in HCl . CLINOCHLORE, *m.*

[1] If yellow in colour it is fayalite.
[2] Sometimes green.
[3] See footnote 3, p. 27.
[4] See footnote 3, p. 27.

2. Not pleochroic. Soluble in acids.
   - *a.* Honey-yellow. Characteristic "peg" structure. Dull polarisation colours. Prismatic cleavage . . . MELILITE, *p.*
   - *β.* Very perfect cleavage along oP. High polarisation colours . . MUSCOVITE, *m* (Sericite).[1]

b. Extinction oblique.

1. Strongly pleochroic.
   - *a.* Green and brown. Prismatic cleavage $\infty P \angle 124°$ . . . . HORNBLENDE, *m.*

2. Not pleochroic.
   - *a.* Dark yellow, rose, or violet in colour. Prismatic cleavage $\infty P \angle 87°$. (Sometimes slightly pleochroic) . AUGITE, *m.*
   - *β.* Brown or green. In addition to the prismatic cleavages there is a very perfect separation along $\infty P \infty$. DIALLAGE, *m.*

D. SMALL FLAKES

I. Colourless.

a. Dull, dark bluish-grey polarisation colours.
   - *a.* Hexagonal plates; usually grouped in tile-like aggregates. Remaining characters resemble quartz . . . . . TRIDYMITE, *h.*
   - *β.* Rectangular tablets with a cleavage along oP and ∞P; soluble in acids . . MELILITE, *p.*

b. Bright polarisation colours.
   - *a.* Perfect cleavage along oP. Flakes resemble muscovite, but are much smaller. Usually radial or felt-like aggregates. Greasy lustre . . . . . TALC, *m* (MUSCOVITE, *m*).

II. Coloured.

a. Dull polarisation colours.
   - *a.* Strongly pleochroic.
     1. Green flakes with very perfect basal cleavage . . . . . OTTRELITE, *a* (?) *m* (?).

[1] Sericite may be distinguished from muscovite by its talc-like appearance and larger flakes. It generally occurs in aggregates.

β. Not pleochroic (sometimes weak pleochroism). Soluble in HCl.

1. Honey-yellow colour. Characteristic "peg" structure. Some sections isotropic . . . . . MELILITE, *p.*

2. Green, irregular flakes. Usually in aggregates; sometimes a weak pleochroism. Basal cleavage . . CHLORITE, *m.*

3. Blood-coloured (sometimes opaque, with black metallic lustre). Hexagonal or irregular flakes. Frequent as a secondary product in the cracks of other minerals . . . . IRONGLANCE, *h* (Hæmatite).

b. Bright polarisation colours. Weak pleochroism.

Extinction straight.

α. Dark brown colour. Cleavage along $\infty \breve{P} \infty$ and $\infty P \angle 124°$ . . . ANTHOPHYLLITE, *r.*

β. Green colours (sometimes dark blue). With difficulty soluble in HCl . . CLINOCHLORE, *m.*

γ. Peach-coloured . . . . . KÄMMERERITE, *m.*

E. FILAMENTS

a. Extinction straight. Colourless . . . SILLIMANITE, *r.*

b. Extinction oblique.

α. Colourless . . . . . TREMOLITE, *m.*

β. Green. Pleochroic . . . . ACTINOLITE, *m.*

F. AGGREGATES

I. Colourless.

a. Granular aggregates (or aggregates of small flakes and tablets).

α. Soluble in acids. Rhombohedral cleavage.

1. The bands of the polysynthetic twinning often somewhat iridescent. Gives off CO_2 when dissolved in acid CALCITE, *h.*[1]

2. Polarisation colours as in the felspars. Deposits SiO_2 when dissolved in acids . . . . . CHABASITE, *c.*

[1] Dolomite and magnesite may be distinguished by being soluble in acids with greater difficulty.

β. Insoluble in acids.	
1. Dull polarisation colours.	
a. Tile-like groups of hexagonal plates (+)	TRIDYMITE, *h.*
b. Mosaic of small grains	CHALCEDONY, *h*, and QUARTZ, *h.*
2. Bright polarisation colours.	
a. Mosaic of small grains (+)	QUARTZ, *h.*
b. Aggregates of small plates resembling muscovite. Basal cleavage	TALC, *m* (MUSCOVITE, *m*).
b. Filamentous and radial aggregates.	
1. Soluble in acids.	
a. With evolution of CO_2	CALCITE, *h*, ARAGONITE, *r.*
b. With precipitation of SiO_2. Bright polarisation colours	ZEOLITES.

II. Coloured.

a. Granular aggregates (or aggregates of small flakes or plates).	
α. Lemon-yellow pleochroic grains (occurs as pseudomorphs in cracks in other minerals and in veins)	EPIDOTE, *m.*
β. Small-grained green aggregates	VIRIDITE.[1]
b. Filaments and radial aggregates.	
a. Green. Sometimes slightly pleochroic.	
1. Structure usually spherulitic	DELESSITE, *m.*[1]
2. „ „ mesh- or net- like	SERPENTINE, *m.*
β. Grass-green or brown filamentous aggregates (pseudomorphs after pyroxene)	BASTITE, *r.*[1]
γ. Dark yellow or brownish aggregates. Evolves CO_2 on decomposition	SIDERITE, *h.*

G. AMORPHOUS SUBSTANCES

1. Clear amorphous glassy substances; yellowish-brown, yellow, or colourless (or green?)	VOLCANIC GLASS.

[1] Viridite, delessite, bastite, are names applied to little-known indefinite secondary decomposition-products.

2.	(*a.*) Colourless, or white, or dark yellow (often stained by oxide of iron to a reddish-brown or yellow colour). Soluble in KHO	OPAL.
	(*b.*) Green	VIRIDITE.
	(*c.*) Yellow, brown, or red	LIMONITE.
	(*d.*) Cloudy grey; semi-transparent . .	KAOLIN.[1]

[1] Kaolin forms aggregates of small crystalline flakes; it also occurs amorphous.

TABLE IV

THE DETERMINATION OF THE CRYSTALLINE SYSTEMS UNDER THE MICROSCOPE

I. The mineral has no action on polarised light. Under crossed nicols all the sections remain dark during a complete rotation of the stage . — ISOTROPIC, SINGLY REFRACTING SUBSTANCES.

a. None of the sections have the characters of crystallographic substances. Absence of all traces of crystalline structure.

b. There are some regular polygonal crystallographic contours. Cleavage, twinning, and usual signs of crystalline structure . . — CRYSTALS OF THE CUBIC SYSTEM.

II. Doubly refracting in polarised light. Between crossed nicols during a complete rotation of the stage of the microscope become four times alternately dark and light. During the latter they are coloured by more or less bright interference-colours . . . . . — ANISOTROPIC, DOUBLY REFRACTING SUBSTANCES.

a. Transverse sections isotropic. In convergent polarised light (the method of Bertrand or Von Lasaulx) transverse sections show an immovable black cross and interference-rings.[1] In anisotropic sections the extinction is straight . . . . . — **Uniaxial.**

[1] The directions in which the sections of the minerals of a rock are cut are always quite accidental, and rarely show symmetrical interference-figures. Moreover, in some very thin sections only the inner part of the area contained by the first interference-ring is seen. The usual appearance is a straight beam or dark line, which may be either one arm of the cross of a uniaxial figure or part of the dark hyperbola of a biaxial figure. In the former case the beam always remains straight and, on rotating the stage of the microscope, moves in the direction of rotation ; in the latter it becomes bent, and its movement is opposite to that of the stage.

1. The transverse isotropic sections are quadrangular or octagonal in shape . — CRYSTALS OF THE PRISMATIC SYSTEM.

2. The transverse isotropic sections are hexagonal, triangular, or 9-angled in shape — CRYSTALS OF THE HEXAGONAL SYSTEM.

b. No isotropic sections. In convergent polarised light certain sections show the emergence of two optic axes and interference-lemniscates intersected by a cross. Rotation of the stage causes the figure to change from a black cross to hyperbolæ[1] . . . . **Biaxial.**

1. In all sections the extinction under crossed nicols is straight (the axes of elasticity coincide with the crystallographic axes). In convergent polarised light, in sections parallel to the pinacoids, the interference-figures are symmetrical and the emergence of two optic axes is seen . . . . . — CRYSTALS OF THE RHOMBIC SYSTEM.

2. Extinction straight only in sections cut from the zone of the orthopinacoid; in all others it is oblique. In convergent polarised light, in sections parallel to the pinacoids, the emergence either of a bisectrix or an optic axis is seen, or unsymmetrical interference-figures (only one of the axes of elasticity coincides with a crystallographic axis; in this case the latter is the orthodiagonal) . . . — CRYSTALS OF THE MONOCLINIC SYSTEM.

3. Extinction always oblique. (No axis of elasticity coincides with a crystallographic axis) . . . . . — CRYSTALS OF THE TRICLINIC SYSTEM.

[1] See footnote previous page.

TABLE V

THE ROCK-FORMING MINERALS CLASSIFIED ACCORDING TO THEIR CRYSTALLINE SYSTEMS

A. Isotropic Substances [1]

I. *Crystals belonging to the Cubic System*

A. Semi-transparent. [2]	
1. The surface appears very rough and varied. Occurs in octahedra, irregular and filamentous or branched aggregates of a violet-grey, grey, or reddish-brown colour (decomposed in H_2SO_4)	Perowskite.
2. Octahedra or grains; not affected by acids .	Spinel.
a. Dark brown or red; metallic lustre .	Chromite and Picotite.
b. Dark green	Pleonaste and Hertzenite.
B. Transparent.	
1. Rhombic dodecahedra [3] or grains. Colour, usually red; sometimes dark-brown or black. Few inclusions. Insoluble in acids . .	Garnets.
a. Red; almost colourless in thin sections	Almandine.
b. Blood-red	Pyrope.
c. Black or dark brown . . .	Melanite.
2. Grains or rhombic dodecahedra (garnetohedra); sections are rectangular or hexagonal. Blue, colourless, grey, black, or brown. Numerous inclusions.	
a. Reactions of NaCl	Sodalite.
b. „ „ $CaSO_4$. Characteristic black border	Hauyne (Nosean).

[1] For amorphous substances, see p. 40. [2] For opaque substances, see p. 25.
[3] Sometimes shows anomalous double refraction.

3. Irregular aggregates or grains; colourless, white, or muddy. Soluble in HCl . . ANALCIME.

B. DOUBLY REFRACTING SUBSTANCES

UNIAXIAL MINERALS

II. *Crystals of the Prismatic System*

1. Polygonal or circular sections. Colourless. Regularly arranged granular inclusions. (Complex double refraction is often seen under crossed nicols) . . . . . LEUCITE [1] (+).
2. Colourless prismatic crystals $\infty P \infty$ and P. Extremely bright, green or red, polarisation colours ZIRCON (+).
3. Coloured acicular crystals. Sometimes in pyramids or grains. Dull polarisation colours.
   - *a.* Black, honey-yellow, or red-brown in colour. Characteristic knee-shaped twins. Double refraction positive . . . . RUTILE (+).
   - *b.* Dark blue; sharp pyramids. Double refraction negative . . . . . ANATASE (−).
4. Prismatic crystals, grains, or flakes. Perfect cleavage along $\infty P \infty$. Colourless or yellow. Soluble in HCl. Double refraction negative.
   - *a.* Colourless; on solution in HCl precipitates silica in fine powder . . . . SCAPOLITE and MEIONITE (−).
   - *b.* Honey-yellow (or colourless). Characteristic "peg" structure. On solution in HCl precipitates gelatinous silica . . MELILITE (−).

III. *Crystals of the Hexagonal System*

1. **Colourless (occasionally coloured).**
   - *α.* Optical sign positive. Insoluble in acids.
     - *α.* Numerous fluid cavities. Grains or bipyramidal crystals. Polarisation colours bright . . . . . QUARTZ (+).
     - *β.* Small hexagonal plates. Characteristic tile-like aggregates. Dull grey polarisation colours . . . . . TRIDYMITE [2] (+).

[1] It is convenient to leave leucite in the prismatic system, which it resembles in form; it appears, however, to be really a monoclinic mineral which has acquired a prismatic form by compound mimetic twinning.

[2] Tridymite may possibly belong to the triclinic system.

b. Optical sign negative. Soluble in HCl.

a. Prismatic crystals (sometimes coloured). Weak polarisation colours.

1. Long prismatic crystals ∞P, P and oP. Transverse jointing along oP. Reactions of P_2O_5 . APATITE (–).

2. Short prismatic crystals ∞P, oP. Reactions of NaCl . . . NEPHELINE (–).

β. Grains; colourless, dark greenish, yellow, or dark red. Greasy or butter-like lustre ELÆOLITE.[1]

γ. Rhombohedra or grains with compound twinning along $-\frac{1}{2}R$. It also shows a fine play of colours or iridescence. Reactions of CO_2 . . . . . CALCITE,[2] (–).

2. **Always coloured.**

a. Long prismatic crystals intensely coloured with bright blue or green (or rose-coloured) tints. Strongly pleochroic . . . TOURMALINE (–).

b. Dove-coloured or brown. Rectangular or hexagonal sections or grains. Cleavage along R and oR. Sections have a well-developed shagreen or rough aspect. Polarisation colours bright. Pleochroism well marked . . . . . CORUNDUM (–).

c. Flesh-coloured (or iron-black with a metallic lustre). Hexagonal plates or irregular flakes. Dull polarisation colours . . HÆMATITE.

IV. *Crystals of the Rhombic System*

1. Optical sign positive.

a. Colourless. Sections octagonal, hexagonal, etc.

α. Rough shagreen-like surface; no cleavage. Soluble in HCl. Characteristic alteration into serpentine or limonite. Clear polarisation colours . . . . OLIVINE (+).

[1] Cancrinite may be readily distinguished from elæolite as it contains $CaCO_3$.

[2] Very nearly allied to calcite are dolomite, magnesite, and siderite; they may be distinguished partly by the rarity of the twin-structure and partly by their being insoluble in HCl, or soluble only with difficulty; the only final test is chemical treatment.

β. Long prismatic crystals: characteristic octagonal sections. Prismatic cleavages intercept at ∠92°. Vertically striated. Polarisation colours usually less bright than in olivine . . . . . ENSTATITE (+).

γ. Filamentous or in acicular prisms without terminal faces. Bright polarisation colours . . . . . SILLIMANITE (+)

δ. Long prismatic crystals with terminal faces. Cleavage parallel to brachypinacoid. Is decomposed in acids when powdered. Dull bluish-grey polarisation colours . ZOISITE (+).

b. Coloured with bronze or yellow tints. Pleochroic.

a. Rough surfaces which appear raised. Characteristic cross-shaped twins . STAUROLITE (+)

β. Long prismatic crystals, broad plates, prismatic cleavages intercept at ∠92°. Usually have octagonal sections. Pleochroism weak; sometimes almost colourless . . . . . BRONZITE (+)

γ. Prismatic cleavages intercept at ∠124°. Resembles hornblende. Occurs in plates with octagonal sections . . ANTHOPHYLLITE (+)

2. Optical sign negative. Strongly-marked pleochroism.

a. Dark brown; occurs as broad plates or needles. Characteristic inclusions of tablets or needles. Prismatic cleavages intercept at ∠92° . . . HYPERSTHENE (−)

Sometimes colourless.

b. Flesh- or rose-coloured. Long tabular crystals. Surface appears very rough ANDALUSITE[1] (−)

c. Violet or blue in colour. Grains and small prismatic crystals. Twinning along ∞P. Characteristic alteration into pinite[2] (Colourless crystals resemble quartz) CORDIERITE (−)

[1] Chiastolite may be distinguished from andalusite by a somewhat [illegible] of black material.

[2] Irregular greenish filamentous material with aggregate polar[illegible]

V. *Crystals of the Monoclinic System*

1. Very perfect cleavage along oP. Plates and flakes. Practically straight extinction.[1]

a. Coloured; polarisation colours dull.

α. Broad plates or small flakes. Pleochroism strong . . . . . **Magnesian Mica Group.**

Optical sign positive.

1. Dark brown or sometimes dark green — BIOTITE.
2. The same, but the plane of the optic axis perpendicular to (∞ P ∞) . — ANOMITE.
3. Brick-red . . . . . — RUBELLANE.
4. Yellow, or light brown. (Very little iron in its composition) . . — PHLOGOPITE.

β. Small plates, aggregates, or crystallites. Sometimes pleochroic . . . **Chlorites.**

Optical sign negative.

1. Flakes and hexagonal plates of a green colour. Soluble in HCl . . — CHLORITE (RIPIDOLITE).
2. Worm-like twisted bands . . . — HELMINTHITE.
3. Rhombohedral crystals soluble in HCl — PENNINE.

Optical sign positive.

4. Peach-coloured or red . . . — KÄMMERERITE.
5. Simple or twinned crystals of a dark green or bluish colour. Pleochroism weak, but stronger polarisation colours . . . . . — CLINOCHLORE.
6. Circular plates of a green colour with polysynthetic hatching along oP. Pleochroic. Numerous inclusions . — OTTRELITE[2] (–).

b. Colourless (sometimes greenish). Bright polarisation colours.

α. Broad plates, as in biotite. Optical axes intercept at a large angle . . . — MUSCOVITE.
(Sometimes iridescent) . . . . — (SERICITE) (–).

β. Small flakes, usually in radial or filamentous aggregates. Angle between the optical axes small. Greasy lustre . . — TALC (–).

[1] Acute bisectrix almost perpendicular to oP.

[2] According to some authors ottrelite belongs to the triclinic system.

2. Prismatic cleavages intercept at ∠87°. Not pleochroic.[1]

Granular crystals; sometimes tabular. Octagonal and hexagonal sections. Prismatic and acicular microliths. Optical sign positive . **Monoclinic pyroxenes.**

Angle of extinction large; 32°, 39°, 54°.

a. Colourless, yellow, greenish-brown, or violet. Occurs as crystals, grains, and prismatic or acicular microliths	AUGITE.
b. In addition to the prismatic cleavage, a perfect lamellar separation along ∞P∞. Brown or green . .	DIALLAGE.
c. Grass-green grains	OMPHACITE (DIOPSIDE).
d. Colourless or light green. Occurs as grains or transversely-jointed prisms	SAHLITE.
e. Colourless; filamentous prisms or radial aggregates. Surfaces appear strongly raised. Soluble in HCl . .	WOLLASTONITE.

Angle of extinction small. About 7°.

f. Dark green or dark brown grains and long prisms. Pleochroic . .	ACMITE.

3. Prismatic cleavages intercept at ∠124°. Strongly pleochroic.

Crystals and grains as in the previous groups or in filaments. Optical sign negative . . **Amphiboles.**

Angle of extinction not more than 18°.

a. Green or brown. Large crystals or grains	HORNBLENDE.
b. Long prismatic crystals without terminal faces; or filaments.	
α. Bluish-green . . .	ACTINOLITE.
β. Colourless	TREMOLITE.
c. Bluish-green grains or microliths. Contains Na_2O	ARFVEDSONITE.
d. Indigo or lavender-blue; occurs as plates, grains, or filaments . .	GLAUCOPHANE (GASTALDITE).
e. Light green fibrous paramorphs after augite and diallage. Aggregate polarisation	URALITE.

[1] Sometimes a faint pleochroism.

4. Colourless grains, plates, and prismatic crystals. Cleavage along oP and (∞ P ∞). Characteristic twinning on the Carlsbad, Baveno, or Manebach types.
   - *a.* Dusty-looking owing to kaolinisation (with development of muscovite). Grey or brown, owing to staining by oxide of iron — ORTHOCLASE (−).
   - *b.* Fresh, glassy, with numerous glass inclusions. Often shows zonal structure . — SANIDINE (−).
5. Dark brown or yellow. Very rough prominent surface. Wedge-shaped crystals or twinned aggregates. Polarisation colours distinguishable with difficulty from the natural colours of the minerals . . . . . — TITANITE (+).
6. Lemon-yellow or yellowish-green. Strongly dichroic. Occurs as plates, needles, grains, aggregates, or pseudomorphs. Generally a secondary formation . . . . . — EPIDOTE (−).
7. Colourless. Very soft. Occurs as grains, plates, or aggregations. Often forms whole rock-masses. Very bright polarisation colours. Iridescent. Cleavage along (∞ P ∞) . . . . . — GYPSUM (+) (SELENITE).

VI. *Crystals of the Triclinic System*

1. Long prismatic crystals or grains. Colourless or blue and pleochroic. Cleavage along $\infty \bar{P} \infty$. — DISTHENE (−).
2. Large crystalline grains with a lath-shaped or fibrous structure. Distinguished from orthoclase by the angle of extinction—15° on oP . . — MICROCLINE (−).
3. Broad plates, tabular crystals, grains, and microliths. Polysynthetically twinned; structure thus caused appears like a series of parallel bands; there may be one set or two transverse sets. The bands are often irregular.
   - *a.* Dusty and grey, due to kaolinisation (with formation of muscovite) . . . — PLAGIOCLASE.[1]
   - *b.* Water-clear or glassy. Numerous glass inclusions. Zonal structure often present — MICROTINE.

[1] The plagioclases may be distinguished by their angle of extinction (compare the tables of Michel Lévy, Hussak, or Rosenbusch). In most cases the plagioclases may be distinguished by their greater solubility in HCl (thus anorthite is the most soluble and labradorite the least), the breadth of the twin lamellæ, and the size of the angle of extinction.

TABLE VI

THE APPLICATION OF THE OPTICAL SIGNS OF MINERALS

I. Optical Sign Positive [1]

A. Colourless.

1. Small needles or small prisms.
   - *a.* Straight extinction.
     1. Tetragonal, prismatic crystals. Very bright polarisation colours . . — Zircon, *p.*
     2. Tabular crystals without terminal faces or filaments. Bright polarisation colours . . . . — Sillimanite, *r.*
     3. Tabular crystals with prismatic jointing. Dull bluish-grey polarisation colours . . . . . — Zoisite, *r.*
   - *β.* Oblique extinction.
     1. Small prisms; often twinned . . — Plagioclase (except Labradorite).
     2. Filaments without terminal faces. Prismatic cleavage $\infty P \angle 124^\circ$. — Tremolite, *m.*
2. Crystalline grains, polygonal sections, broad plates, tabular crystals, etc.
   - *a.* Uniaxial.

   Insoluble in acids.
     1. Water-clear grains, or bipyramidal crystals. Bright polarisation colours . . . . . — Quartz, *h.*
     2. Tile-like aggregates of hexagonal plates. Dull bluish-grey polarisation colours . . . . — Tridymite, *h* (?).

[1] When it is difficult to determine the optical sign, this table may still be made use of by supposing firstly the mineral to be positive, and comparing its other characters with those of the minerals here given; and then similarly comparing it with the minerals in the negative series.

β. Biaxial.

1. Extinction straight.

a. No cleavage. Rough shagreen-like surfaces. Characteristic alteration into serpentine and limonite. Soluble in HCl . OLIVINE, *r.*

b. Prismatic cleavage. Vertically striated. Insoluble in HCl. Polarisation colours usually lower than the last . . ENSTATITE, *r.*

2. Extinction oblique.

a. Prismatic cleavage ∠87°. Angle of extinction large—39° or more. Sometimes twinned on ∞ P ∞ . . . . . AUGITE, *m.*[1]

b. Polysynthetic twinning giving rise to a banded appearance. The lamellæ are all parallel, or there may be two transverse series . PLAGIOCLASE, *a*[2] (except Labradorite).

c. Grains or octagonal sections with well-marked (but optically anomalous) double refraction. Characteristic distribution of granular black inclusions . . . LEUCITE, *p* (?).

B. Coloured.

a. Needles or prisms.

1. Black or yellowish-brown needles (rarely grains) . . . . . RUTILE, *p.*
2. Yellow and brown microliths, with large angle of extinction (above 39°) . . AUGITE, *m.*
3. Brown prismatic crystals. Characteristic cross twins. Pleochroic. Straight extinction . . . . . STAUROLITE, *r.*
4. Brown, semi-transparent, wedge-shaped crystals and grains. Polarisation colours distinguishable with difficulty from the natural colours of the mineral . . TITANITE, *m.*
5. Small blue pyramids . . . . ANATASE, *p.*

[1] Thick sections may be slightly yellow.

[2] See footnote, p. 27.

β. Octagonal and hexagonal sections. Broad plates or grains.

1. Oblique extinction. Yellowish, greenish, and violet in colour. Prismatic cleavages intercept at ∠92° . . . . . BRONZITE, *r.*

II. OPTICAL SIGN NEGATIVE

A. Colourless.

1. Prismatic crystals.

α. Uniaxial. Some hexagonal isotropic sections.

1. Long prismatic crystals. Reactions of P_2O_5 . . . . . APATITE, *h.*
2. Short prismatic crystals. Reactions of NaCl . . . . . NEPHELINE, *h.*

β. Biaxial. No isotropic sections.

i. Extinction straight. Plates. Rough surfaces. Cleavage along ∞P . . ANDALUSITE, *r.*

ii. Extinction oblique.

1. Long tabular crystals; usually without terminal faces. Insoluble in acids. . . . . DISTHENE, *a.*
2. Microliths, usually twinned. Soluble in HCl. Angle of extinction 16°-21° (on $\infty \bar{P} \infty$) . . . LABRADORITE, *a.*
3. Microliths simple. Angle of extinction 5° in relation to the edge oP : (∞P∞). Insoluble in HCl. ORTHOCLASE (SANIDINE), *m.*

2. Polygonal sections. Grains. Broad plates and large prismatic crystals.

α. Uniaxial. Extinction straight. Rectangular sections isotropic.

1. Bright polarisation colours. Cleavage along ∞P∞. When dissolved in acid precipitates powdery SiO_2 . . SCAPOLITE, *p.*
2. Dull polarisation colours. Cleavage along oP and ∞P. Characteristic "peg" structure. When dissolved in acid forms gelatinous SiO_2 . . MELILITE, *p.*

β. Biaxial.

i. Extinction oblique.

1. Dusty and kaolinised, or glassy and clear with zonal structure and numerous glass inclusions. Sections hexagonal. Twinning on the Carlsbad, Baveno, or Manebach types . . . . ORTHOCLASE, *m* (SANIDINE).

2. Grains with a lath-like or fibrous structure MICROCLINE, *a*.

3. Agrees with No. 1, but is polysynthetically twinned. The angle of extinction is 16°-21°. Soluble in HCl . . LABRADORITE, *a*.

ii. Extinction straight. Grains and polygonal sections. Characteristic alteration into pinite . . . . . CORDIERITE, *r*.

3. Broad plates and aggregates.

α. Granular aggregates. Compound twinning along $-\frac{1}{2}R$. Cleavage in Rhombohedra. Soluble in HCl, with evolution of CO_2 . CALCITE, *h*.

β. Broad plates or aggregates of flakes, with very perfect basal cleavage . . . MUSCOVITE, *m*.

γ. Radial aggregates of small flakes. Greasy lustre . . . . . TALC, *m*.

B. **Coloured.**

1. Tabular crystals. Small Prisms. Strongly pleochroic.

α. Extinction oblique. Blue tabular crystals, without terminal faces . . . . DISTHENE, *a*.

β. Extinction straight.

1. Green and blue. Long hexagonal prisms. Frequently in radial aggregates. Hexagonal sections isotropic . . . TOURMALINE, *h*.

2. Flesh-coloured rhombic plates, with very rough and raised surfaces . . . ANDALUSITE, *r*.

3. Brown microliths. Cleavage along $\infty P \angle 92°$ . . . . . HYPERSTHENE, *r*.

4. Small lemon-yellow prisms . . . EPIDOTE, *m*.

2. Polygonal Sections. Grains. Plates.

a. Uniaxial.

1. Honey-yellow. A characteristic "peg" structure. Soluble in HCl . . MELILITE, *p.*

β. Biaxial.

Extinction straight.

1. Brown or dark green plates, with very perfect basal cleavage. Absorption . BIOTITE, *m.*
2. Blue grains and polygonal sections. Characteristic alteration into green fibres of pinite. Sometimes colourless CORDIERITE, *r.*

Extinction oblique.

3. Brown or green. Prismatic cleavages intercept at ∠124° . . . . HORNBLENDE, *m.*
4. Lemon-coloured granular aggregates (pseudomorphous and secondary alteration-products) . . . . EPIDOTE, *m.*
5. Bluish-green flakes and crystals, with basal cleavage . . . . . CLINOCHLORE, *m.*

THE END

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